A Review of Fuel Science and Engineering Courses at MIT, the University of Sheffield and the University of Leeds, England.

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Introduction

Traditionally Fuel Science and Engineering has been regarded, from an educational viewpoint, as something of a hybrid subject which cannot be easily accommodated within the accepted framework of separate academic disciplines. In general faculties of science tend to treat the subject as an extension of Physical and Organic Chemistry with considerable emphasis on basic fuel properties and the chemistry of combustion. Engineering faculties on the other hand often provide courses in both Mechanical and Chemical Engineering Departments which concentrate on specific areas of fuel utilization and processing. Courses in Mechanical Engineering Departments deal mainly with only the physical and thermodynamic aspects of the combustion of fuels in F. C. engines and gas turbines. Chemical Engineering Departments in general do not provide specific courses on Fuels but do include a considerable amount of basic material relevant to the Fuel Processing area in several standard Chemical Engineering courses. Consequently it is the exception rather than the rule to find well-balanced schemes of study in the areas of Fuel Science and Engineering. Very few academic institutions provide a broad-based education in all aspects of fuels ranging from resources and recovery through to utilization and pollution control.

The current wave of interest and concern in all matters relating to the national energy situation provides sufficient justification for closely examining the educational programs of the scientists and engineers who will be needed to meet the demands in this area. It would be somewhat ironic if the new technologies and industries proposed to overcome the nations fuel supply problems were themselves subjected to a supply problem of adequately trained personnel. The question of whether or not our educational institutions currently provide appropriate programs for the number of personnel required in this area, still remains open. It is perhaps worth noting that several large American companies are currently recruiting graduate-level fuel scientists and engineers directly from U.K. Universities. Also it appears inevitable that as we turn to progressively more difficult fuels, the environmentally acceptable extraction, processing and utilization will lead to an increased requirement for professionals at all levels in the fuel and energy sector. A satisfactory answer to the questions raised here can of course only be obtained by conducting a detailed market survey of both the sources of supply of and demand for fuel scientists and engineers at both graduate and undergraduate levels. It is in this area that the professional societies could play an important role.

It is not the objective of this paper to provide answers to these questions of supply and demand, nor to address the more fundamental questions relating to the role of universities in regulating or controlling the supply in the interests of particular professions. Based on the premise that some changes may be desirable to improve either or both the quality and quantity of Fuel Science and Engineering courses, three examples of University Departments currently offering schemes of study in this area are presented which represent three alternative levels of commitment to education in this subject area. At MIT the Department of Chemical Engineering has traditionally maintained a strong graduate program in Fuel Engineering which represents only one specialist subject area in a comprehensive Chemical Engineering curriculum. The Department of Chemical Engineering and Fuel Technology at the University of Sheffield has maintained a very strong commitment to both

subjects at graduate and undergraduate levels. The Department of Fuel and Combustion Science at the University of Leeds offers both graduate and undergraduate degree schemes devoted exclusively to the subject of Fuels.

Fuel Engineering Courses at MIT

In common with many Engineering Schools in Departments of Mechanical and Nuclear Engineering at MIT offer specialized graduate courses which are related to certain areas of Fuel Engineering. Courses in Combustion, Thermal Power System, Energy Conversion and Nuclear Fuels fall into this category. The Department of Chemical Engineering is one of the few departments in the country to offer a coordinated scheme of study at the graduate level in Fuel Engineering. This scheme of study is completely optional and represents only one possible area of graduate specialization amongst a total of twelve Chemical Engineering topics. An integrated program in this area, leading to an M.Sc, requires a total of 66 credit hours at least 42 of which must normally be obtained from the following list of courses subjects:

Subject	Credit hours
Energy Technology	9
Chemical Engineering Thermodynamics	12
Mechanics of Fluids	9
Catalysis and Catalytic Processes	9
Absorption and Catalysis	9
Chemical Reaction Engineering	9
Principles of Combustion	9
Seminar in Air Pollution Control	9
Seminar in Fuel Conversion and Utilization	9
Radiative Transfer	9
Nuclear Chemical Engineering	12

In addition, a research thesis is required and the Department Fuels Research Laboratory together with the MIT Energy Laboratory provide excellent facilities for research on a wide range of fuel processing and combustion topics. Normally the general requirements for an M.Sc. degree can be met within one academic year.

The general philosophy in respect to education in Fuel Engineering is to treat the subject as a specialized area of Chemical Engineering. Courses are presented only at graduate level and require a firm background in the general principles of Chemical Engineering. However, the courses are available to undergraduate students in their senior year as restricted electives. This approach to graduate education in Fuel Engineering inevitably leads to a considerable degree of specialization. The very nature of graduate-course work usually precludes much of the less intellectually demanding qualitative material associated with some of the more pragmatic aspects of Fuel Engineering . At MIT the areas of specialization reflect the department's strong interest in Chemical Engineering aspects of Fuel Processing. Combustion and Air Pollution. Several other engineering schools offer graduate courses which cover other important aspects of Fuel Engineering such as Resource Recovery, Thermal Power Engineering and Energy Management. In general, it is felt that even though very few graduates obtain degrees specifically in Fuel Science and Engineering, there is a sufficient pool of specialist graduates to meet the demands of the upper level managerial, research and development areas of the fuel and energy sector.

The Department of Chemical Engineering and Fuel Technology, University of Sheffield, England.

Before discussing the structure of the graduate and undergraduate courses offered by the Department of Chemical Engineering and Fuel Technology at the University of Sheffield, it is worthwhile to point out the general differences, particularly in respect of entrance requirements, between U.K. and American Universities. In general U.K. students are a year older than their American counterparts on entering a university. They will have spent two years studying three or four subjects appropriate to the area of university study they wish to pursue. For instance, most students wishing to enter Chemical Engineering Schools will have studied Maths, Physics and Chemistry. Each university and university department is then free to set whatever entrance requirements it feels necessary for specific degree courses. Eligibility for entrance is then judged on the basis of individual students performance in national examinations conducted by independent examining bodies. Entrance requirements are consequently somewhat more stringent in the U.K., and the students are equipped to commence their undergraduate degree courses at a higher academic level than freshmen in American Universities. As a result most undergraduate courses are only three years in duration, leading to the Bachelors degree. By the time of entrance, students have already chosen their subject areas, and specialists courses in the appropriate subjects are given during the first year.

The scheme of study at undergraduate level, offered by the Department of Chemical Engineering and Fuel Technology at the University of Sheffield, consists of courses during the first two years with optional subjects in the final undergraduate year. Students are required to obtain satisfactory results in all prescribed subjects at the end of the second year before being allowed to proceed to the final year. Progress is monitored essentially by formal written examination at the end of each year. The results of these examinations determine whether or not the student is considered for an Ordinary or Honours degree.

First year subjects are mostly extension of Maths, Physics and Chemistry, general engineering courses and introductory courses to Fuel Technology and Chemical Engineering which represent about 20% of the total course load. These courses are designed to equip the student for the more advanced courses in the second and final year's scheme of study. Laboratory classes in the first year introduce students to many of the practical aspects of Fuel Technology including properties and testing of solid, liquid and gaseous fuels. During the second year the prescribed scheme of study consists of courses in,

Fuel Technology	Mechanical Engineering	Maths
Chemical Engineering	Elector-Technology	Chemistry

The Fuel Technology and Chemical Engineering courses occupy approximately 50% of the course work. At this stage, Chemical Engineering courses deal essentially with the fundamentals of Heat, Mass and Momentum Transfer at quite an advanced level. The Fuel Technology courses deal with some of the general aspects of Fuels including handling and processing, and introduction to some of the more practical problems associated with the combustion of different types of fuels. After successfully completing the first two years of prescribed undergraduate courses, students then have the option of choosing between final year schemes of study in either Chemical Engineering and Fuel Technology or Environmental Chemical Engineering. The prescribed courses of study for these two options are given below;

Either (i) Chemical Engineering and Fuel Technology

Chemical Engineering Operations	Fuel Processing
Control and Instrumentation	Direct Electricity Generation
Nuclear Reactor Engineering	Combustion Theory
Business Economics	Refractions Technology

or (ii) Environmental Chemical Engineering

Chemical Engineering Operations	Project Evaluation with respect to Pollution Control
Control and Instrumentation	Medical and Legal aspects of Pollution
Environmental Chemical Engineering	

together with any three of the following advanced topics:

Fluid Dynamics
Advanced Combustion Theory with Gas Dynamics
Heat Exchanges
High Temperature Chemical Engineering
Process and Project Engineering
Advanced Topics

In addition during the final year students are required to undertake either an experimental investigation or a design study of some problem of Chemical Engineering or Fuel Technology.

These course details clearly show that the subject of Fuel Technology can be included as a major element in a Chemical Engineering curriculum at undergraduate level. However, it should be realized that much of the course material on fuels is contained in the final year of study, and as such, the overall effect is to provide basic core of Chemical Engineering courses around which the subjects of Fuel Technology, and in particular, Combustion are handled primarily from a Chemical Engineering and Processing point of view.

In common with most other U.K. University Departments, the Department of Chemical Engineering and Fuel Technology offers both Master's and Doctorate research programs requiring no formal course work. However an advanced course on Combustion Science and Pollution Control is also offered, which leads to the award of a Diploma or Master's Degree by examination. The course consists of two full terms of lectures, seminars and experimental work on topics which include:

Physical Chemistry of Combustion
Connective Heat Transfer
Radiative Heat Transfer
Theory and Technology of Combustion Process
Minor Constituents of Flames and Combustion Gases
Combustion Noise and Oscillations
Flame and Plasma Reactors
Open Flames, Flares and Incinerators, Plume Dispersion
Furnace Refractories
Measurement and Control in Flames (Experimental Techniques)
Mathematical Models of Combustion Systems.

In addition, students prepare a dissertation in either a design study or a research project, which is completed after the course work and can serve as an introduction to a Ph.D. course.

This Master's course is open to graduates in engineering, physics, chemistry and mathematics.

The Department of Fuel and Combustion Science at the University of Leeds.

Instruction and research in fuel science have been provided by the University of Leeds since 1906, and courses are currently offered at the undergraduate level in Fuel and Energy Engineering and in Fuel and Combustion Science. The courses are offered by the Department of Fuel and Combustion Science which is the only University Department in the U.K. to offer undergraduate schemes of study devoted exclusively to the subject of fuels. The department providing these schemes of study is the founding member of the Houldsworth School of Applied Science. The school itself consists of five departments which, although independent in themselves, have so much in common that they have elected to work together as a group. These departments are Fuel and Combustion Science, Chemical Engineering, Metallurgy, Ceramics and Mining and Mineral Sciences. The school organization allows the various departments to share lecture rooms, the library, common rooms, workshops and many items of costly equipment which could not easily be provided separately. In addition, the departments provide carefully tailored service courses in specific subject areas for students from other departments within the school.

The Department currently offers four undergraduate degree programs,

- B. Sc. Fuel and Combustion Science
- B. Sc. Fuel and Energy Engineering
- B. Sc. Chemistry/Fuel and Combustion Science
- B. Sc. Fuel and Energy/Management Studies

The first two of these schemes involve only the Fuel and Combustion Science Department. Both are essentially three year courses and have a basic theme in common but are varied to cater to the individual ability and intentions of the student. The Fuel and Combustion Science course contains rather more basic science than the Fuel and Energy Engineering course, which as its name implies, is biased more towards engineering and technological aspects. Broadly, but not exclusively, the former is intended to equip graduates for entry into the research and development sectors of the industries supplying and using fuels and the latter is intended for future designers and builders of plant and equipment for the large-scale processing or use of fuels.

The last two undergraduate degree schemes are combined courses offered jointly with the Departments of Chemistry and Management Studies. The Chemistry/Fuel and Combustion Science scheme of study allows the chemistry-minded student to carry this subject further while at the same time receiving sound training in the science of fuel and combustion. The combined course in Fuel and Energy/Management studies is aimed at providing both a firm technological and engineering appreciation of fuels and energy for students wishing to follow conventional courses in Management Studies. This combination of courses is hoped to provide the correct blend of technological and managerial knowledge required for the new generation of fuel and energy managers.

The Honour's degree schemes of study for both Fuel and Combustion Science and Fuel and Energy Engineering are given below.

First Year- courses are essentially common for both degree schemes.

Fuel and Energy Sources	Maths
Fuel and Energy Utilization	Physics
Materials Science	Physical Chemistry
Computational Techniques	

Second Year- again the majority of fuel courses are common, the only differences being in the subsidiary subjects.

Fuel and Combustion Science		Fuel and Energy Engineering
	Combustion Technology *	
	Fuel Processing and Flow of Materials *	
	Power Generation I *	
	Instrumentation and Control *	
	Fuel and Energy Economics *	
	Applied Physical Chemistry *	
	Heat Transfer I *	
	Chemical Engineering (Unit Operations) *	
Physics		Mathematics
Chemistry (Organic)		Engineering (Mechanical and Electrical).

(* Common Courses)

Third Year- all courses are given by the Department.

Fuel and Combustion Science		Fuel and Energy Engineering
	Combustion Aerodynamics and Heat Transfer *	
	The Efficient Use of Energy *	
	Management and Organization of the Energy Industries *	
Combustion and Explosion		Petroleum and National Gas Engineering
Petroleum and National Gas Science		Fuel and Combustion Plant Design
Coal and Carbon Science		Power Generation II

(* Common Courses) In addition to the above courses, students are required to conduct an experimental research project on some aspect of fuel and combustion science or energy engineering.

Courses for the combined degree schemes in Chemistry/Fuel and Combustion Science and Fuel and Energy/Management Studies consist of combinations of some of the above courses with selections of standard courses in the Departments of Chemistry and Management Studies, respectively.

Schemes of study are also offered at graduate level leading to

- M. Sc. Combustion and Energy
- M. Sc. Environmental Pollution Control.

The latter course is run in conjunction with several other university departments, though combustion and fuels-related pollution aspects are covered by the department. The former course is offered by the Center for Combustion and Energy Studies which draws upon the expertise of the Departments of Fuel and Combustion Science, Mechanical Engineering and Physical Chemistry. Both of these graduate programs take one complete academic year and include both course work and a research exercise.

Discussion

The major differences in approach to education in Fuel Science and Engineering in the three Departments discussed here are ones of scope and breadth of coverage. Treatment at graduate level without any prior introduction to the subject of Fuels leads inevitably to a considerable degree of specialization, usually in some area amenable to a qualitative and analytical approach, such as combustion. The inclusion of Fuel Science and Engineering courses at undergraduate level can readily be integrated into 9 Chemical Engineering curriculum without seriously affecting the basic elements essential for education in Chemical Engineering. This approach can eliminate the need for specialization in one particular area and can lead to a well-rounded appreciation of the engineering significance of fuels. Undergraduate schemes of study devoted exclusively to the study of fuels provide an extremely broad training in all aspects of Fuel Science and Engineering. The major advantage of this approach is that it provides sufficient coverage of many important qualitative, practical and technological aspects in all areas

of Fuel Science and Engineering. Hence not only are the more academically inclined students able to pursue careers in research and development, but the more practically-minded students are well prepared to enter the operational side of many industries making or using fuels. It is often at this level where many important decisions affecting fuel and energy usage are made particularly in the small to medium size industries.

It is always easier and usually safer to alter the superstructure rather than the foundation of any particular institution. Consequently it is felt that any charges deemed necessary in the education of Fuel Science and Engineering in the U.S.A. will take place predominately in graduate schools by alteration of existing courses or implementation of new courses. However, it is felt that many of the important subjects, particularly fuel and energy utilization, can best be included at undergraduate level.

Fuel Science and Engineering courses can easily be integrated into a Chemical Engineering curriculum and the provision of such courses could certainly help to provide the technological background so often missing in graduate level courses.

FUEL CHEMISTRY
Undergraduate and Graduate Fuel Science and Engineering Education at West Virginia University

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Introduction

Fuels science and engineering at West Virginia University refers to those educational activities in engineering and science programs whose subjects deal with the extraction and utilization of fossil fuels. In this broader sense, fuels science and engineering are involved with all aspects of fossil fuels. In particular, they deal with combustion, conversion, coking and the utilization of coal, oil shale and tar sands. In a narrower sense, the subject covers chemical and physical changes involved in fuel utilization. The purpose of an educational endeavor in this subject area is to develop the potential in able and interested people for solving complex problems of fuel utilization. The need for such educational programs is expected to intensify in the near term.

West Virginia University is a land-grant university and the comprehensive state university for West Virginia. Tuition is one of the lowest in the nation and admissions are open. Self-selection by students provides an academically oriented student body as described by college-bound test scores and high school grades. As the comprehensive state university, WVU offers programs in professional schools and graduate departments. Agriculture, dental, engineering, law, forestry, medicine, minerals, nursing, and pharmacy schools are supported by graduate programs in basic sciences.

The university is in Morgantown, Monongalia County; a county which customarily ranks first or second among the counties in the state in coal production. West Virginia has ranked first or second in coal production among the states for many years. Other energy resources are also recovered commercially.

Need

The need for fuels-oriented programs is variously viewed. In the scientific and engineering disciplines, the state, regional, and national dependence on imported fuels are considered important reasons for study; faculty have acquired appropriate interests and skills over the years, and student demand has remarkably strengthened over a five year period. Personnel in the science and engineering programs are additionally motivated by their interest in new and improved understanding of nature; a desire to publish, and the increased availability of university, state, and federal support.

Jobs are avialable in industry, government, and academia. Pressure from recruiters has been strong and effective. Students and faculty alike have received offers of high salary and optimum working conditions. An important co-effect has been the disruption of traditional ivory tower inclinations and reduction of leisure to ruminate among ideas and over problems.

History of On - Going Effort

Different programs throughout the university have a different historical pattern of response to the perceived educational needs in fuels. Programs vary greatly in their longevity, levels of sophistication, and orientation toward a specific fuel. Some stress science and some are engineering oriented.

As an example of a science department, geology is of special interest. The faculty offer three courses in which coal is of primary concern. Two of these courses - Coal Geology and Coal Petrography- were approved formally within the last two years. Considerable jurisdictional discussion had ensued between faculty in geology and those in the College of Mineral and Energy Resources. A single geology course is offered in Petroleum Geology. Geological research on fuels is centered on characterization and on resource or reservoir definition. A new and major research effort on gas from Devonian Shale is currently underway. The fuels work in geology is often done in cooperation with the West Virginia State Geological and Economic Survey.

In engineering programs, course offerings centered on fuels are extensive. Mining, petroleum, chemical, mechanical, and mineral processing engineering as subject areas are largely committed to design, operation, construction and research dealing with fuels extraction and utilization processes.

Chemical engineering offers two courses on coal conversion at the undergraduate level. Mineral processing engineering offers another sequential undergraduate course on conversion and a graduate course in synthetic liquid fuels. Electrical, mechanical, mining and petroleum engineering have substantial research interest and funding in problems of fuels appropriate to their general charge.

Fuels Research

Before 1970, little activity was apparent in fuel research. From the early 1960's, the state had supported efforts from a semi-autonomous Coal Research Bureau to find, develop, and increase markets for West Virginia coal. The fund supported academic research and technological development to a certain extent. Since 1976, however, a considerable and increasing portion of an ever-larger budget has been allocated under a new charter to academic researchers working in an independent mode. The administration of the research grant procedure has been placed under the direction of a Provost and a committee of university faculty and administrators.

The effect has yet to be evaluated. However, many excellent academicians chose to apply their expertise to the solution on fuels oriented problems. Broad, university-wide, representation among the researchers has become apparent. As part of this effort, the chemistry department and the physics department expanded their research efforts on fuels. Chemistry has aimed toward fuels combustion mechanisms and has additional support from industry and government. Supported by state funds, physics is investigating magnetic effects in pyrite as a function of temperature.

Additional Response to Need

Two goals were visualized for the WVU fuels science and engineering programs in the light of society's need for energy and chemical feedstocks and the students need for preparation in a challenging and rewarding career.

Society's need is likely to be met by utilization of a plentiful fuel resource or by the conversion of a plentiful reserve to a resource, The areas of need to be served are for process plant and utility fuel, metallurgical coke, substitute natural gas and synthetic petroleum. The area of challenge is extended through the science and technology of utilization but with particular attention to the chemical reactions involved.

The fuels science and engineering programs at WVU are career oriented. Orientation for a career is to be viewed within the broad framework of degree candidates who will solve technological problems which are real and present. The expectation is high that the careful selection of students, especially at the graduate levels, and the stress in the programs upon principles and their rigid application will produce future problem solvers.

The educational philosophy at the university has been one of permissiveness, flexibility, and encouragement rather than coercion in the motivation and direction of students.

Organization

Organizational responses have been quite varied. Some programs cross organizational lines while others are within academic units.

Fuels science programs and courses at WVU are concentrated in the College of Mineral and Energy Resources; the College of Engineering, and the College of Arts and Sciences. The College of Mineral and Energy Resources was authorized in January 1975 to offer programs leading to the Bachelor of Science, and Master of Science Degrees in mineral processing engineering, complementing long existing degree programs in mining engineering and petroleum engineering. In 1976, access to the interdisciplainary Ph.D degree with the College of Engineering was authorized. Two options are stressed: one is in coal preparation and the other is in coal conversion. Considerable support in these efforts were required and obtained from the Department of Chemical Engineering.

EDUCATION IN FUELS ENGINEERING AT THE UNIVERSITY OF UTAH

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The Fuels Engineering Program at the University of Utah was established in 1946. The need was recognized for students with specialized training in fossil fuel technology . The B.S., M.S., and Ph.D. degrees were offered through the Department of Fuel Technology which became part of the State College of Mines and Mineral Industries. The Department rapidly distinguished itself for research and graduate study, although student enrollments were not large. Since its inception, 13 B.S. degrees, 12 M.S. degrees, and 44 Ph.D. degrees have been granted. During recent years, the program has grown in size and the undergraduate program has been revitalized and strengthened. Recent enrollment trends are shown in table 1. The name of the degree has been changed from Fuel Technology to Fuels Engineering and the program is now part of the Department of Mining, Metallurgical and Fuels Engineering.

Undergraduate Program

With the influx of students into the undergraduate program, the curriculum has been revised and new courses have been instituted. Fuels students take a common core program with Chemical and Metallurgical Engineers during the Freshman and Sophomore years and about one-half of the Junior years. This consists of the Liberal Education requirements of the University; general, organic and physical chemistry; mathematics through calculus and differential equations; engineering physics; and engineering courses such as process engineering, thermodynamics, strength of materials, mass transfer, fluid mechanics and heat transfer. During the Junior and Senior years the student takes required advanced undergraduate fuels courses from the list shown in table 2. Eleven of the 17 courses are required. The student also must fill technical elective requirements from fuels or related courses.

The energy problems of the United States have brought attention to energy studies and attracted many students to fuels engineering. Several scholarships are available to outstanding students. This has attracted students of high ability to the program.

"Energy and Man" is a course designed for non-science or engineering students as part of the Liberal Education program. Enrollments were low when it was first introduced in 1970, but in recent years it has been offered each quarter to large enrollments. The purpose of this course is to provide non-technical students with a background concerning energy problems so that they may function more effectively as citizens and as energy consumers.

Graduate Program

Graduate students enter the program with degrees primarily in chemical engineering or chemistry. Chemistry majors must take several basic engineering courses in addition to the graduate degree requirements. About one-third of the course work for an advanced degree must come from outside fuels engineering. The graduate committee of each graduate student must also have representation from outside fuels engineering. Graduate courses are shown in table 2.

Major areas of research for graduate degrees at the present time include liquefaction and gasification of coal, analysis of coal-derived liquids, upgrading of synthetic liquid fuels, tar sand processing, coal structure and reactions, and catalysis.

SUMMARY

The Fuels Engineering program attempts to train professionals with a basic background in engineering and the physical sciences and specialized training in the chemistry and processing of fossil fuels. It is experiencing rapid growth at both the undergraduate and graduate level. The teaching and research faculty has grown to nine persons. Future growth is difficult to predict due to many uncertain factors. The demand for professionals with this type of training is expected to be strong.

TABLE 1. - Fuels Engineering Enrollment

	73/74	74/75	75/76	76/77
Freshman	1	4	12	18
Sophomore	1	6	8	12
Junior	2	2	8	6
Senior	1	2	4	7
Total undergraduate	5	14	32	43
M.S. candidates	7	7	10	15
Ph.D. candidates	14	13	16	17
Total graduate	21	20	26	32

TABLE 2. - Fuels Engineering Courses

Lower Division

Introduction to Process Engineering
Energy and Man
Fundamentals of Process Engineering
Physical Chemistry of Mineral Systems

Advance Undergraduate and Beginning Graduate

Senior Project
Field Trip
Introduction to Heterogeneous Catalysis
Recovery of Fossil Fuels
Chemicals from Petroleum
Catalyst Preparation, Characterization, and Testing
Catalysis Laboratory
Chemistry of Fossil Fuels
Mineral Fuel Testing
Mineral Instrumentation
Conversion of Coal to Other Energy Forms
Energy Resources and Their Utilization
Modern Petroleum Refining
Flames, Combustion and Combustion Reactions
Fuels and Lubricants
Laboratory Safety
Corrosion of Metals, Theory and Practice

Advance Graduate

Theoretical and Applied Aspects of Catalysis
Kinetics and Interretation of Catalytic Reactions
Chemicals from Petroleum
Fundamental of Coal Liquefaction and Gasification
Properties and Reactions of Coal and Coke
Oil Shale and Bituminous Sands

Education in Fuels and Combustion: Needs for the Future and the Pennsylvania State University Program

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INTRODUCTION

Fuels Science and Engineering is a wide ranging topic that has been described as the interdisciplinary subject par excellance. The total scope is often divided into three prime topics: Production of fuels; Fuel preparation and Benefication; and Utilization. Production covers mining of coal, and petroleum and natural gas reservoir engineering. Preparation covers cleaning, crushing, grinding, and related aspects of coal benefication, with refinery engineering and related operations for oil and gas. Utilization is the facet that fuels education most commonly focuses on, and is primarily concerned with combustion and related uses of all fuels in all applications. The proper content of fuels education is discussed in more detail below: the broad scope of the study of fuels from the scientific to the engineering aspects is often titled Fuel Technology*.

PERSPECTIVE

To the outsider viewing Fuel Technology in the context of todays energy famine it must surely appear to be the subject of greatest technical importance in the curriculum of any university or similar training institute. Such a view is not supported by the facts, however. Fuels education is in a curiously anomalous position. Although fuel technology has been a rewarding subject for study and application for many decades -- one might even say, centuries -- it has still never had the academic prominence or even recognition of other technologies such as chemical engineering, metallurgy, ceramics, and so forth. There are believed to be less than half a dozen universities or institutes in the world with formal academic programs leading to degrees in Fuel Technology. Fuel Science, or Fuels Engineering, and the numbers, in fact, have been declining. There is likewise no central recognized platform or journal for the total range of the topics of concern in Fuel Technology. Interest is scattered over many semi-specialized Society divisions and journals. In a word, Fuel Technology does not, at present, have the recognition of being a formal academic discipline with a formal body of knowledge (even though this exists) that practitioners should know if they are to claim the authority of speaking as fuel technologists. Only in specialized cases such as power and propulsion systems (a minority branch of fuel technology) does something like a formal training exist. Industrial principles and applications, which represent over 40% of national energy use, are mostly unknown and untouched. Industry has therefore had the habit in the past, partly by default, of appointing fuel engineers, managers, supervisors, or controllers, from those in the ranks of other engineering professions such as chemical, metallurgical, ceramic, and mechanical engineering.

The problem has been that since fuels was everyone's business, it was no-one's business. In each individual segment of industry the topic of fuel use was essentially an appendage, with individual solutions to very similar problems being developed in the different process sectors -- ferrous and non-ferrous operations, glass, ceramics, refinery stills, cement manufacture, and so forth.

*"Technology" is used here in the same sense as in M.I. of Technology, or C.I. of Technology, etc.

In university curricula, where process metallury and ceramics, and the like, are still thought to be important, fuels are discussed mostly in the context of the single industry. In the other engineering areas, emphasis tends to be solely on power systems and, as observed by Smith and Stinson (1) 25 years ago: "It has been (our) observation that the general treatment of fuels and combustion is many times slighted in engineering curricula, even though the combustion process is a vital link in power cycles. Frequently the topics of fuels and combustion are presented, in part, through courses in steam power, internal-combustion engines, heating and ventillating, and laboratory, with little coordination or continuty of the material presented in the various courses. The result many times is an incomplete coverage of either fuel technology or combustion, and usually a meager concept is obtained of the actual chemical processes of burning." This observation would still seem to be substantially true. Only in the propulsion specialties (gas turbines and rockets) would there seem to have been any significant change.

This fragmentation of fuel technology, however, does not seem to have been too significant in the past; it would be hard to say that industrial development has really been hindered by this. So does it matter for the future? The answer would seem to be a decided: Yes! The pattern of the distant industrial past was a generally accelerating use of fuel, initially of wood and charcoal and subsequently of coal, during which there was ample time (decades) for the most part to develop necessary techniques by essentially untrained inventors and developers (who often became highly skillful by on-the-job training). The pattern of the more recent past (the last 50 years) was then a process of further industrial development based, first, on oil, then on gas. The trend was to more easily used and proportionately cheaper fuels. A return to coal or coal-based fuels means reversing that trend. The fuels will be more expensive and more difficult to use. It is not simply a matter of reverting to past technologies. The use of oil, and particularly gas allowed (largely ad-hoc) improvements in precision of firing furnaces: temperature control, metering, burner cycling, and so forth; and operators will continue to expect, or demand as essential, similar precision and ease of firing. The scale of the problem, in terms of fuel tonnages consumed has also increased: total energy consumption has almost quadrupled in the last half century. There are also environmental constraints that makes return to coal so much more difficult.

As a result of this pattern, there is indeed evidence now of an increasing demand for fuels specialists with a much higher level of education. The past practice of on-the-job training (which led to many re-inventions of the wheel) can be expected to disappear. It takes too long; it can leave too many gaps in knowledge; it is likely to be too specilized which makes for inflexibility; and there is usually time only to attain a relatively elementary level of understanding that can be far short of what is required today.

The demand must increasingly be met by training at the university level, but this presents several problems. There are too few schools at present with even a pretence at a reasonable coverage of the field of knowledge that can be called Fuel Technology, and these schools are almost unknown to large sections of industry, to other universities, and to virtually all prospective students. There is even ignorance in some academic quarters of what academic or formal training coverage can be provided in the field of fuel technology so that plans to expand course coverage can be held up or will be incomplete on account of that lack of knowledge, and lack of necessary teaching manpower. (This, further, ignores the present constraints on university funding that makes curriculum enlargement difficult to impossible in may cases.)

It is understood that this Meeting (on Fuels Science and Engineering Education) at which this paper is presented is designed to develop solutions to these problems. In this paper, contributions to three aspects are presented.

WHAT IS FUEL TECHNOLOGY?

The broad scope of fuel technology (or science and engineering) is outlined in the Introduction. It can be summarized as: the study of fuel in science and practice. For the development of curricula, something with greater precision and more detail is required for setting the boundaries to the field and for identifying individual subject or topics.

Fuel technology is broadly concerned with the utilization of fossil fuels and of their manufactured and related dervatives, including the process of manufacture of the secondary fuels (by gasification and liquefaction). It should also include some degree of study of the sources and reserves of coal, oil, gas, and other potential fuels (including shales, tar sands, solid waste, etc.). Also significant are the physical and chemical properties, methods of analysis, chemical structure, and methods of preparation (cleaning, drying, grinding, distillation, screening, etc.).

Utilization is still the core of fuel technology. This means: production of power; use for processing; and secondary fuel manufacture for ultimate use as gas, liquid, or solid, in power and processing. Utilization depends on knowledge of fuels reactivity -- Reaction Kinetics applied to solid, liquid, or gaseous fuels. It also requires applied knowledge of fluid mechanics (combustion aerodynamics) and heat transfer (mainly radiative). Specific technological subjects of importance that represent application of fundamentals include, in particular: flame chemistry; flame propagation theory; carbon and coal reactions; reactor and flame holding theory; furnace analysis; radiative properties of flames; and scale-up methods for pilot plants.

These topics are set in schematic perspective in Figs. 1 and 2. Figure 1 illustrates the overall process of utilizing fuel to deliver a useful end product. Input includes knowledge of fuel and raw material sources, preparation, and supply to the reactor. Output lists power, process use, manufactured fuels, and effluents. Reactor operation, or requirements for understanding their operation, is illustrated in Fig. 2, which shows the relationship between the basic sciences and their engineering application.

Supplementary to the above, training in fuel technology must also include such sufficient understanding of the power and process operations themselves that the mechanical and other aspects of the furnaces and engines makes sense. This brings in such additional topics as: heat engine thermodynamics; furnace thermodynamics; refractory behavior and selection; heat treatment principles (with emphasis on the iron/carbon diagram); and effluent control (such as, air pollution from combustion sources).

Fuels Education at Penn State

In spite of the wide ranging scope of Fuel Technology, at the Pennsylvania State University all aspects are covered in one Department or another. Relevant Departments or Sections include Chemical Engineering, Mineral Processing, Petroleum and Natural Gas, Mining, Mineral Economics, and the Fuels Science Section of Materials Science and Engineering with some combustion and power aspects in Mechanical Engineering. In addition, the Coal Research Section is a research and administrative unit that ties together a number of closely related research activities on coal and carbons.

Most of the teaching and research activities, however, are centered in the Fuel Science Section of the Materials Science and Engineering Department. The original program started nearly 50 years ago in the Department of Fuel Technology, essentially as an outgrowth of graduate courses in coal carbonization and fuel utilization in the Department of Metallurgy. Over the period 1921-1931 these original courses developed into an Option in Fuel Technology, in that Department, with undergraduate instruction in fuel testing and calorimetry, coking, classification of coals, liquid and gaseous fuels, carbonization and processing of coals, and combustion and utilization of solid, liquid, and gaseous fuels. The strength of this option was such that, in 1932, a separate Department of Fuel Technology was created, granting simultaneously both undergraduate and graduate degrees (B.S., M.S. and Ph.D.). In the years since then, a total of 180 students have graduated with the bachelors degree, 83 with the masters degree, and 115 with the Ph.D.

About 10 years ago the undergraduate curriculum was closed because of very low enrollment. It was then obvious to everyone, except for the faculty in the Fuel Technology Department, that there was no further future in coal, and little further need for fuel technologists dealing with utilization of oil and gas. Reflecting that view, the State Legislature dropped support of a special coal research funding program. In industry, fuel was so easy to burn and so cheap that no special knowledge was required for its (inefficient) use. It is symptomatic of those times that, as remarked above, fuel engineers in industry were almost universally drawn from the ranks of the other engineering professions, without training in fuels, and with little awareness of the body of knowledge that did exist in fuel technology; and this, to some extent, is still the case today.

In 1969, the first (predicted) shortages in interstate pipeline gas supply showed up. In 1970-1971, the (predicted) peaking of native oil supplies from the lower 48 states also occurred. The timing on contraction of support for fuels education was clearly superb. Since then, the well-known controversy has been raging whether the fuel shortages are real or the result of some conspiracy. Wtih the understanding that this is a real problem, the question of what is needed in fuels education is reopened with dramatic force. The central significance of the problem derives from the central significance of energy in driving the industrial machine and modern civilization, and the awareness that without fuel you are out of business.

In spite of the dropping of the undergraduate program, in time for the start of the fuel shortages, (more accurately, the program dropped us), senior level and graduate programs nevertheless continued. In the early years, all the work the Department, both undergraduate and graduate, was focussed almost entirely upon coal and coal-related topics -- what might be called, without prejudice, coal technics. Following World War II, however, the scope of all programs was enlarged to cover the classical range of fuel technology topics: focussing on utilization, but with coverage increased to include gaseous and liquid fuels, and on materials derived from fuels, notably carbons and graphites. Coal preparation and beneficiation that were part of the original Fuel Technology Department program were moved about that time into a new Department of Mineral Preparation.

About the time of the demise of the undergraduate curriculum, the original Department of Fuel Technology ceased to be a Department, and was absorbed (with a small name change) as the Fuel Science Section in the (new) Department of Materials Science and Engineering.

The current scope of the teaching activities in the Fuel Science Section is illustrated by Table 1 which lists, with brief descriptions, the present course offerings of the Section. (The 400 numbers are senior-graduate courses, and the 500 numbers are graduate courses). There are presently 7 faculty in, or associated with the Fuel Science Section (several of whom also have additional teaching reqiirements in materials and related subjects). There is also a related course in coal petrography (Geol. 421). There are also other closely related courses on combustion, gas turbines, and more conventional mechanical engineering courses on power plants, thermodynamics, and so forth, in other departments. Including aspects of petroleum production and refining, mineral economic aspects and related topics, there is a total of some 15 to 20 courses available at the senior and graduate levels that can be properly defined as part of Fuel Technology.

The research interests are of even wider scope. These include studies of gas/carbon reactions, gasification of carbon and coal, liquefaction of coal, fuel cells, and solar energy converters. The research has been described in about 450 research papers in the past 20 years.

Fuels Education in the Future

If Fuel Technology is sufficiently important for the future, the pattern of the past would suggest that new programs can be expected to come into being, with courses covering part or all of the material outlined in the Section defining Fuel Technology. A decade ago this would already have happened and new Departments would have come into existence. That this has not yet happened is almost certainly due to a number of factors. The most obvious has been lack of funds. There has also been uncertainly as to the real nature and scope of the fuels problem, and uncertainly over the real Federal commitment towards fuels. The topic has lacked activists in the manner of the Environmental Spokesmen of a decade ago -- after all, fuels have been with us a long time: isn't it really a simple problem, and don't we already know all we need to know? Energy activists have tended to promote nuclear electric (which must always be a minor energy source) or new developments in solar, geothermal, and the like. Also, there has not been a recognized combustion engineering community or Institute to speak for the fuels area as a whole.

A more suble problem derives from the current small size of the fuels community. A program that will attract students, and supporters, must be visible, credible, and viable. Without the existence of a widely-recognized academic discipline a single Department of Fuels lacks visibility, which makes recruiting difficult. The program can also lack credibility: "If it's as important as that, why aren't there more Departments?" is a good question. Without more Departments, the subject is barely viable. It was on these grounds that M.W. Thring on becoming Professor of Fuel Technology at Sheffield University (England) in 1950 immediately entered (successful) negotiations to have the Department recognized as a joint Department of Chemical Engineering.

Counters to these three problems are now forthcoming. The problem of visibility (and significance) was partly solved by the belated recognition by the Network News Anchor men that an energy problem of some sort really did exist. Credibility will appear when a number of fuels departments, options, centers, programs, or sections come into being: this will also confer the necessary viability to the academic programs.

The necessary centers would already appear to be in embryonic existence. This has been established in the following way. We have carried out a search of

the listings on fuels and fuel-related courses in the Course Catalogs of Universities in North America. We have identified a total of about 500 such courses offered in about 120 Universities. Although this averages 4 courses per University about half only offer 3 courses or less. About 1/3 of the courses are offered by only 14 institutions, each offering 9 or more such courses. These Universities are identified in Table 2 together with the total number of courses they offer. Table 2 also shows two other columns. In the Course indentification, all conventional (though necessary) courses in transport phenomena, heat transfer, reaction or chemical kinetics, power systems thermodynamics of heat engines, and the like, were omitted. Topics on industrial combustion engineering, flames, propulsion, combustion aerodynamics, pollution from combustion, and so forth, were included. In a first breakdown of the total, the established engine, gas turbine, propulsion, and related power and aerospace topics were designated as a Group II. Subtracting from the total leaves Group I (listed in Table 2), which are mostly the more industrially oriented combustion, pollution, and fundamental flames courses. Inspection of these then shows that fuels and combustion was evidently the major topic in some courses, but was of minor or secondary interest in the rest. Group IA in Table 2 is the number of courses identified as having fuels and combustion as the major topic (within what could be identified by the course descriptions).

Before discussing the breakdown, some caveats and disclaimers are in order. Course offerings of most universities were examined, but not all (we were unable to obtain the Harvard University Catalog, for example). The discrepancy between course description and course content is well known and requires no comment. Selection of the courses (or their omission) involved a value judgement that was difficult to exercise in quite a number of cases, particularly where course descriptions were vague, wide ranging and cut across several topics; members of individual universities may well make a somewhat different selection. The breakdown does not differentiate between senior level courses (that can indicate strength in teaching) from graduate level courses (that can indicate strength in reasearch). A clear pattern nevertheless exists. There is evidently a core of about a dozen Universities with strength in fuels or fuel-related activities. About half are more engine or propulsion oriented (Cal Tech, Michigan, Purdue, Wayne State in particular). The other half are more fundamentally/industrially oriented, or showing equal weight with engine/propulsion aspects (notably Penn State, Georgia Tech, IIT, MIT).

It would appear, then, that a Fuel Technology and Combustion Engineering community and constituency does exist. There can be a question as to how it should grow. There are constraints: funding or the lack of it is the most important, but there is also a shortage of manpower. What else could happen if the subject has been short-changed for so long? It is also not clear whether the center of gravity of Fuel Technology properly lies in the mining, mechanical, chemical, or even metallurgical or some other engineering area. Perhaps the best means of expanding Fuels programs would be by creating Options or Minors in Fuel Technology inside existing Departments of different disciplines. This would not overload the available manpower, and would either provide time for an evaluation of the subject matter to see where it best lies or it would solve the problem by having a different bias -- mechnaical, or chemical, or some other -- in different institutions. This may prove indeed to be the only feasible method of providing adequate coverage of the whole area of Fuel Technology. In course of time, such Options and Minors might expand into Sections inside the parent Department, and ultimately the Sections could become Departments. An organic growth based on real need rather than a forced growth based on expectations is obviously a preferred behavior. It is probably not necessary or even desirable for this to be accompanied by the development of the usual paraphanalia of Departments, rigid

curricula, Institutes, Journals, and the like, so long as there are sufficient centers of Fuel Technology that recognize each other and whose standing is acknowledged and made use of. The criteria of visibility, credibility, and viability must be met.

CONCLUSIONS

A coherent, significant, and important body of knowledge representing Fuel Technology does exist, together with a practical reason for its existence. Between half a dozen and a dozen Fuel Technology centers also exist already, at least embryonically. An academic framework for the necessary instruction and research also exists. It would seem that Fuel Technology is ready to come of age and to be recognized as a significant academic and practical discipline in its own right.

Reference

1. Smith, M.L. and Stinson, K.W., "Fuels and Combustion", McGraw Hill, 1962.

Acknowledgements

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Table 1

Courses in Fuel Science

F.Sc. 421 Flames. Fundamentals of premixed and diffusional combustion.

F.Sc. 422 Combustion Engineering. Principles of industrial combustion and gasification engineering.

F.Sc. 424 Energy and Fuels in Technological Perspective. Critical examination of present-day energy technology.

F.Sc. 430 Air Pollutants from Combustion. Pollutant-forming processes; pollutant potential of various fuels and combustors; combustion modification and pollution control.

F.Sc. 431 The Chemistry of Fuels. Origins and properties of the fossil fuels: coals, oils, gas. Coal liquefaction and gasification.

F.Sc. 506 Carbon Reactions. Heterogeneous reactions of carbons. The scientific base for coal gasification.

F.Sc. 512 High Temperature Kinetics and Flame Propagation. Equilibria and rate processes in hot gases; flames; detonations.

F.Sc. 520 Thermodynamics and Kinetics of Fuel Efficiency. Thermodynamic and kinetic constraints on efficiencies of thermal systems; efficiency ratios; furnace analysis; radiation in furnaces, applications and examples.

F.Sc. 522 Flame Dynamics in Combustors. Analysis of mixing and reaction in high intensity combustion chambers.

Table 2

Number of Course offerings in Fuel Technology at Different Institutions

T - total Course offerings in Fuel Technology

I - Courses on flames, combustion, pollution, etc., and non-engine or propulsion topics

IA - as the major subject

	T	I	IA
Cal Tech	12	5	3
Cincinnati	9	8	8
Georgia Tech	16	13	11
IIT	10	8	7
MIT	13	9	7
Michigan	12	6	3
Minnesota	9	4	4
N. Carolina State	9	4	3
Penn State	20	17	16
Princeton	10	7	7
Purdue	10	4	1
Stevens	8	7	4
Utah	14	14	12
Wayne State	10	7	5
Totals	162	113	91

Note: A total of 500 courses in Fuel Technology were identified offered at 120 different universities and similar teaching institutions. About half offer only 3 courses or less. The 14 institutions listed above offer about 1/3 of all the courses.

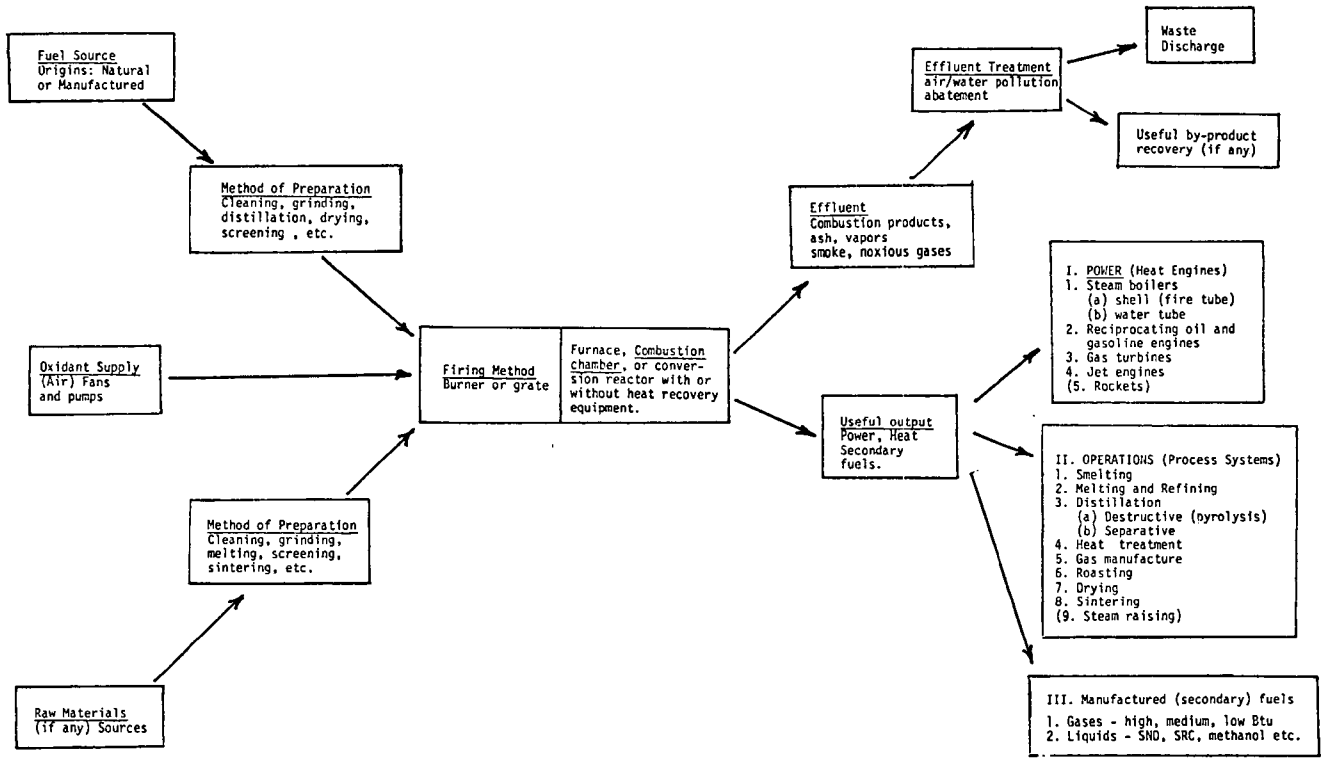

Fig. 1 - Schematic Representation of a Combustion Engineering Operation with Principal Applications (Useful Output)

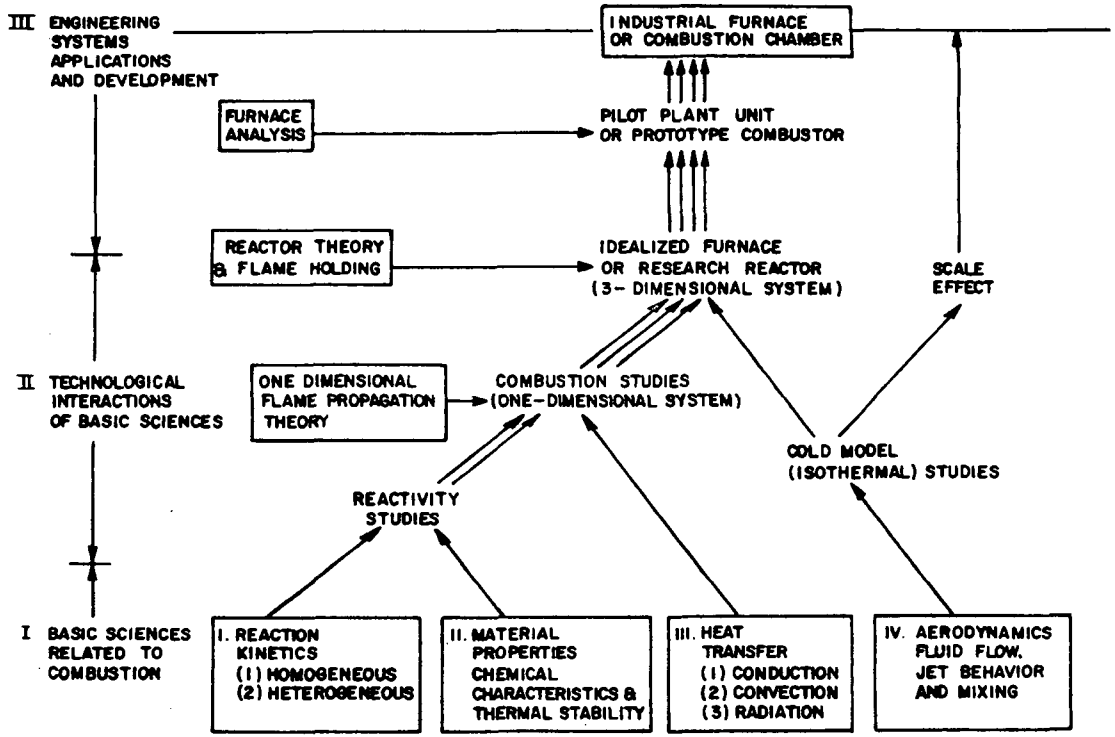

Fig. 2 - Schematic breakdown to illustrate the information flow required for a complete understanding of industrial furnace or combustion chamber behavior. Understanding rests on the four basic sciences: I, Reaction Kinetics; II, Materials Properties; III, Heat Transfer; IV, Aerodynamics. The diagram also illustrates the general relationship between science, technology, and engineering.